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Item unique identification capability expansion: established process analysis, cost benefit analysis, and optimal marking procedures

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

MBA PROFESSIONAL REPORT

ITEM UNIQUE IDENTIFICATION CAPABILITY EXPANSION: ESTABLISHED PROCESS ANALYSIS, COST BENEFIT ANALYSIS, AND OPTIMAL MARKING PROCEDURES

December 2014

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The purpose of this Master of Business Administration project is to identify possible expansion capabilities, by researching the most cost-effective two-dimensional barcode technology known as an item unique identification that will allow for tracking Department of the Navy assets from cradle to grave. While the Navy is not 100 percent complete, the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics mandated that all new tangible and legacy items over $5,000 and/or serially managed, mission critical, or controlled by inventory, must be serialized and registered by 2010. There are two methods that the Navy can use to mark such items: intrusive and nonintrusive. For legacy items, the best method to mark an item would be nonintrusive, due to the criticality of maintaining the integrity of the item for safety reasons. Thus, it was determined that the best marking procedure for legacy items would be metal foil tags, generated by a contracting company, since they are the most cost-effective, nonintrusive marking method.

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LIST OF ACRONYMS AND ABBREVIATIONS

1D	one-dimensional
2D	two-dimensional
AIDC	automatic identification data capture
AIS	automated information system
AIT	automated identification technology
ASCII	American Standard Code for Information Interchange
AT&L	acquisition, technology and logistics
AUSD	Assistant Undersecretary of Defense
BEA	Business Enterprise Architecture
CAGE	Commercial and Government Entity Code
CBA	cost benefit analysis
CIC	Combat Information Center
CFO	chief financial officer
CO2	carbon dioxide
DOD	Department of Defense
DoN	Department of the Navy
DPM	direct part marking
DUNS	Data Universal Numbering System
ECC	Error Correcting Code
ECE	electro-chemical etching
EDM	electrical discharge machine
EID	enterprise identifier
EOSS	Engineering Operational Sequencing System
F	Fahrenheit
FOD	foreign object debris
FY	fiscal year
GAO	Government Accountability Office
IAC	issuance agency code

IBM	International Business Machines
IEC	International Electrotechnical Commission
ISO	International Standardization for Organization
IUID	item unique identification
JIC	Joint Inflation Calculator
LCD	liquid crystal display
LCDR	Lieutenant Commander
LCS	littoral combat ship
LT	Lieutenant
MFR	manufacturer
MIL-STD	military standard
Mm	millimeter
NCCA	Naval Center for Cost Analysis
Nd	neodymium-doped
NPS	Naval Postgraduate School
NSLC	Naval Sea Logistics Center
NSWC	Naval Surface Warfare Center
OUSD	Office of the Under Secretary of Defense
Psi	pounds per square inch
RCA	Radio Communications of America
SER	serial number
SGSI	stabilized glide slope indicator
UID	unique identification
UII	unique item identifier
UPC	Universal Product Code
UV	ultra-violet
YAG	yttrium aluminum garnet
YVO4	yttrium orthovanadate

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LCDR Jarred L. Posada: I would like to thank my wife, Melyssa, for pushing me to fight for what is right and not letting me give in because there was an easier route. To my daughters, Tyana, Jordyn, and Annabelle, thank you for being that spark that always reminded me that no matter how anything else plays out, I will always have you to put that smile on my face, and that is priceless.

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I. INTRODUCTION

A. BACKGROUND

On July 29, 2003, the Acting Under Secretary of Defense for Acquisition, Technology, and Logistics (AUSD AT&L) mandated that as of January 1, 2004, all newly acquired, tangible items must contain an item unique identification (IUID) marking (Office of the Undersecretary of Defense for Acquisition, Technology and Logistics (OUSD AT&L) 2004). The IUID markings are required on all items that are worth $5,000 or more, but items that are less than $5,000 in value and are serially controlled, mission critical, and are deemed by the receiving activity to have IUID markings. Figure 1 is a decision tree that helps identify the items under $5,000 that should receive an IUID tag. According to OUSD AT&L, the IUID marking must be “globally unique and unambiguous, ensures data integrity and data quality throughout its life span, and supports multi-faceted business applications and users” (2004, p. 3).

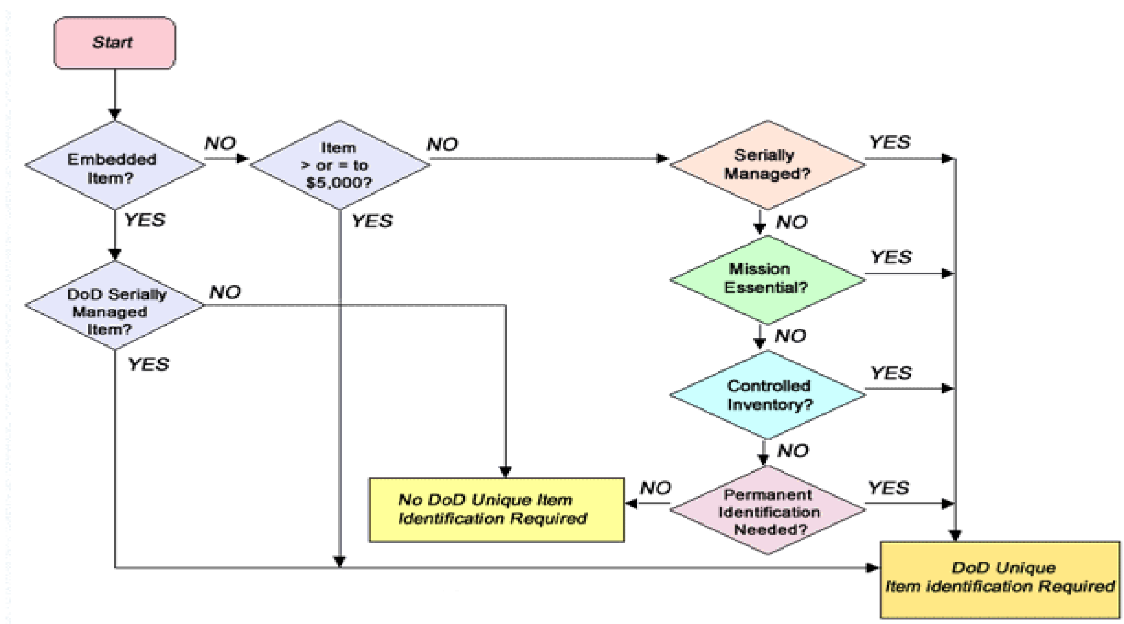

Figure 1. Decision Tree to Uniquely Identify Items under $5,000 (from OUSD, 2004).

The Department of Defense (DOD) purchases over $90 billion in inventory each year, which equates to more than $24 million dollars each day. The DOD was concerned that it did not have a way of accounting for all DOD physical property and equipment purchased with taxpayer money. For example, in 2004, the Government Accountability Office reported a $1.2 billion discrepancy between the items that the U.S. Army shipped and the items received in Afghanistan (Government Accountability Office [GAO], 2004).

In order for Congress and federal managers to ensure that the funding allocated to the armed services was being utilized as efficiently and effectively as possible, a better accountability of tangible items needed to be established. The IUID program was initiated due to the Chief Financial Officer (CFO) Act of 1990, an act that was established for the civilian sector, and the subsequent Government Reform Act of 1994 (OUSD AT&L, 2004). The 1994 Government Reform Act was enacted in order for the DOD to be audit ready. The CFO Act and the Reform Act would "improve the DOD's financial management, promote accountability and reduce cost and emphasize results oriented management" (OUSD AT&L, 2004, p. 3).

The DOD is following the commercial business industry by wanting to produce auditable financial accounting documents. IUID is one method that will help the DOD become audit ready. Dr. Douglas A. Brook, a former AUSD Comptroller/DOD CFO and Naval Postgraduate School (NPS) professor, once said in a lecture at NPS that in order to be audit ready, the DOD is supposed to be able to produce documentation for a desk, at NPS, from its inception to when it arrived at the school house (Brook, 2014). The IUID markings will provide purchase, inventory, and maintenance information from cradle to grave, which is just what auditors will look for once the DOD is audit ready.

The Littoral Combat Ship USS *Fort Worth* (LCS 3) is one of the first ships in the Navy to have the IUID program implemented. Currently, the IUID markings are polyester sticker types that are being placed directly on the equipment. From discussions with Naval Sea Logistics Center (NSLC) IUID technicians, the adhesive on the stickers have proven to be a problem, however, since they can easily be peeled off the equipment or peel off due to wear and tear caused by extreme heat when stored/used in the engine room, or from sun and salt water getting on the equipment when exposed to the environment. The biggest concern for the NSLC IUID technicians are IUID stickers being placed on equipment on the ship's fantail/flight deck, which can become foreign object debris (FOD) hazard for aircraft operations.

IUID expansion capability is required to ensure that all items required to have an IUID tag are able to maintain that marking for the lifespan of the equipment, regardless of the environment. NSLC is looking at possible new technology and equipment which may help improve upon its IUID capability and streamline the IUID program.

B. PURPOSE

The purpose of this Master of Business Administration (MBA) project is to conduct a cost benefit analysis (CBA) on the different technologies and markings available commercially off the shelf. Emphasis will be placed on the marking types, since they will need to withstand environmental climate changes, as well conditions associated with a shipboard environment.

C. METHODOLOGY

The following methodology was implemented in this research:

- Review IUID implementation regulations and instructions.
- Conduct a site visit to USS *Fort Worth* LCS 3 to evaluate and review the existing IUID tagging process.
- Conduct a CBA on different marking methodologies.
- Provide recommendations to NSLC on the most cost-effective marking technology in order to expand the IUID program within the DoN.

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II. ITEM UNIQUE IDENTIFICATION

A. INTRODUCTION

IUID is the benchmark for the DOD to have total asset visibility and improving its item management and accountability in order to be audit ready (OUSD AT&L, 2004). In 2009, the DOD established the Business Enterprise Architecture (BEA) to ensure that the department was following the regulations and policies set forth by the OUSD AT&L. The BEA was designed to transform the way DOD conducts business practices. The BEA will ensure the proper resources and materiel are delivered to the warfighter in a timely manner—around the world. The BEA helped the DOD to maximize its accountability operations by integrating the architecture across joint organizations. The BEA framework assisted the DOD in adapting commercial business operations, strengthened the Departments' financial management, and secured its information technology capabilities which resulted in increasing the buying power of the DOD (OUSD AT&L, 2004). While the IUID process is not directly related to the BEA, it is however another tool in the overall changing business enterprise model that the DOD has adopted. IUID will help the DOD distinguish one item from another, track the item from cradle to grave, including acquisition and maintenance information, and improve the business processes and applications within the DOD (OUSD AT&L, 2004). Figure 2 depicts how the IUID process tracks an item from cradle to grave, thus improving the DOD's inventory system. The process starts at the Requirement step, when the DOD contract reflects the contractor's responsibility for ensuring that a DOD-compliant IUID tag is placed on the item. The Create/Generate step is when the industry suppliers/manufacturers assign a unique IUID data component, compatible with the supply chain, and physically places the IUID tag on the item. The Capture process is when the IUID data is recognized by the DOD accountability and inventory system as belonging to the department. The Use process is when the item is received at the end user's command and it is functional. The Dispose process is when the IUID information tag is terminated at the time that the item is disposed (OUSD AT&L, 2004).

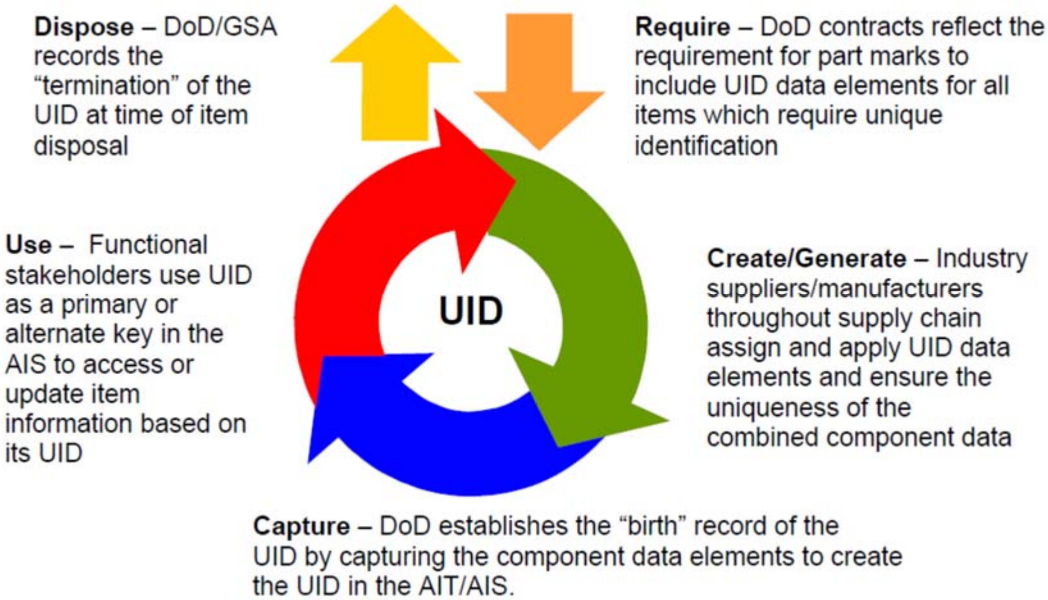

Figure 2. IUID Life Cycle (from OUSD AT&L, 2004).

B. IUID HISTORY AND BACKGROUND

The following section will provide the some historical significance with identification and tracking of items through the evolution of the marking process with the one dimensional (1D) and two dimensional (2D) barcodes, and the Universal Product Code (UPC). It is through the invention of these barcodes that we are able to conduct IUID marking and tracking today.

1. Barcodes and Universal Product Code

The evolvement of IUID originated from the barcodes that were invented in 1948 by the education, grocery, and railroad industries (Goodman, 2010). The UPC was developed from the barcode after it was successfully used for two decades in the grocery industry (see Figure 3). It revolutionized the grocery industry because once the code was scanned; the item and the price were recognized by the grocery stores' registration system.

Figure 3. Universal Product Code (from OUSD AT&L, 2004).

In 1971, Radio Communications of America (RCA) acquired the bull's-eye barcode patent from Norman Woodland and Bernard Silver. Silver and Woodland are best known as developers of the barcode technology, who together introduced the bull's-eye barcode system at a grocery industry convention (Goodman, 2010). International Business Machines (IBM) representatives were also at the convention and were impressed by the technology. They quickly realized that one of the barcode's inventors, Norman Woodland, had been working for IBM since 1951 (Goodman, 2010). Woodland was quickly removed from his current position and given the project of creating a similar code to that used by RCA. In 1973, Woodland developed the UPC code, which was adopted as the industry standard barcode. In 1974, the industry saved hundreds of millions of dollars due to improved inventory accuracy and processing speeds (Goodman, 2010).

2. One-Dimensional to Two-Dimensional Barcodes

The 1D barcode came as a result of the UPC and was limited to 10 characters. As more and more industries used the 1D barcode, a more sophisticated symbolism was used, called Code 128, as shown in Figure 4.

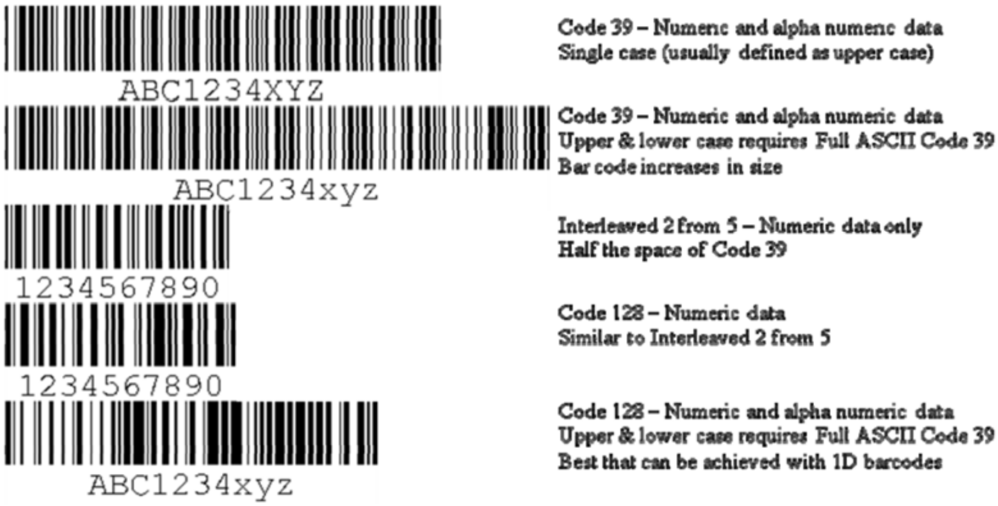

Figure 4. 1D Barcode Types (from Goodman, 2010).

Code 128 was still limited in the number of combinations that could be used with numbers and alphabet characters. The capacity of Code 128 was still 10 characters, which included a combination of the numbers zero through nine and lower- and upper-case alphabet letters (Goodman, 2010). The amount of data that can be stored in the barcodes is limited in capacity, so, in 1988, Dr. David Allais, an internationally recognized expert in the fields of barcoding and automatic identification, created the 2D barcode, Code 49, which can hold a greater amount of information, since the code is made up of white and black 1D barcodes stacked up against each other (Goodman, 2010). With the 2D barcode, much more information could be stored such as the item's manufacturer, its history, and its ultimate location. The 2D's ability to store more information opens up the possibility of using a 2D barcode on an IUID tag. Figure 5 depicts the difference in data structure from the 1D, with data only along one dimension to the 2D, where data flows along two dimensions.

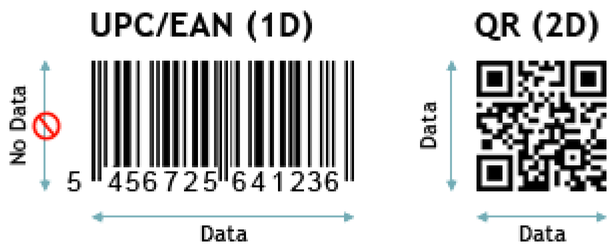

Figure 5. 1D vs. 2D Barcodes (from Schottmuller, 2011).

3. ECC200 Data Matrix

The Error Correcting Code (ECC) 200 was developed by International Data Mix, Incorporated and the National Aeronautics and Space Administration (Goodman, 2010). It was developed as a more reliable data matrix than the 1D UPC as the matrix can be coded with numerically or with text and it can have error correction codes, which are often used to increase reliability where even if one or more cells are damaged so it’s unreadable, the message can still be read.

In July 2003, the DOD selected the ECC200 Data Matrix to be used as the IUID barcode, since the Data Matrix barcode had already been accepted by, and was compatible with, many worldwide businesses. The compatibility stems from the International Organization for Standardization and the Electrotechnical Commission (ISO/IEC), formed in 1987, and was established to ensure, that there are international IT standard activities and to avoid duplicative or possibly incompatible standards (Goodman, 2010).

The 15434 syntax was adopted by the DOD and made it policy, under Military Standard 130N (MIL-STD-130N), for all IUID markings to be 15434 syntax-compatible (Goodman, 2010). The 15434 syntax is used in business sectors around the world due to its information security standards.

4. Unique Item Identification

When the DOD adopted the ECC200 barcode to be used as the IUID markings, it wanted to ensure that it would be unique, unambiguous, and permanent through the life span of the item being marked (Goodman, 2010). The IUID syntax format consists of a format code, delta identifiers, an enterprise identifier (EID), and a serial number, just as in Figure 6. The unique item identification (UII) markings are able to track and locate the equipment, as well as track equipment maintenance records. Currently, there are two kinds of UII format codes that will end up on the equipment as shown in Figure 7.

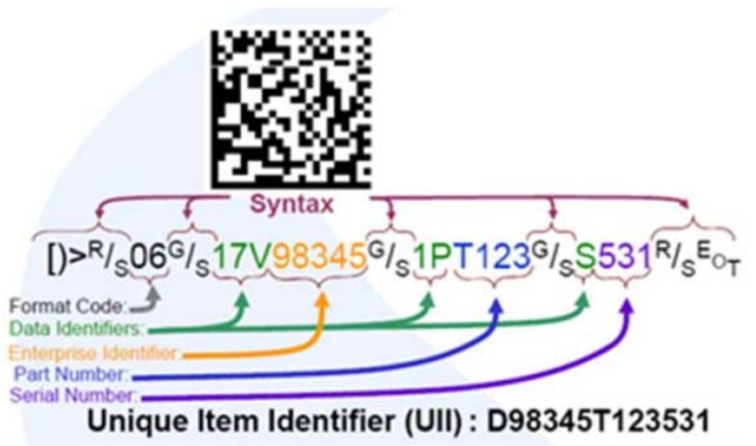

Figure 6. UII Composition (from MacDougall, 2008).

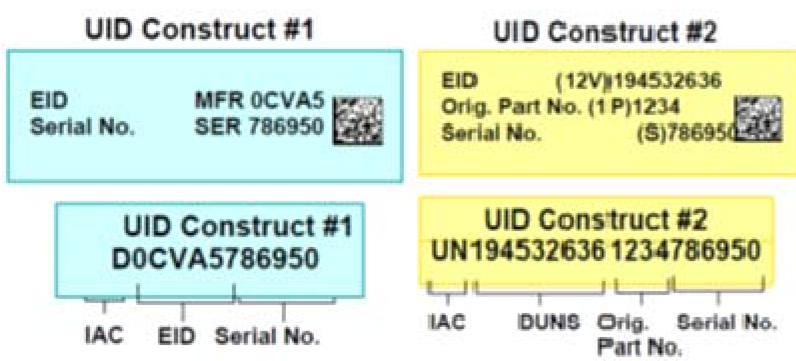

Figure 7. UID Constructs 1 and 2 (from OUSD AT&L, 2004).

The unique identification (UID) 1 composition is for serialized equipment. These items are assigned both a unique and sequential number within a specific organization (Goodman, 2010). The first construct includes an issuance agency code (IAC), which is a unique identifier for the item, a commercial and government entity code (CAGE), and a sequential serial number that is unique to the specific organization (Goodman, 2010).

The UID 2 composition is constructed by placing the item serialization within a part. The second composition does not have a unique serial number, so the original part number is added to the current serial number in order for it to become unique. The second construct also includes an IAC and a Data Universal Numbering System (DUNS), which is an EID. The first UID composition is preferred to the second composition because of its small footprint and the information retrieved from the first UID is more precise (Goodman, 2010).

IUID is the name given to the ECC200 barcoding system that is used by the DOD (Goodman, 2010). The UII being incorporated into the IUID is what differentiates the IUID, used by the DOD, from the UID, which is primarily used commercially.

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III. MARKING LEGACY ITEMS

A. INTRODUCTION

In September 2011, the Deputy Assistant Secretary of the Navy of Expeditionary Programs and Logistics Elements, with the recommendation of the IUID Center at the Naval Surface Warfare Center in Corona, California, released a *DoN IUID Marking Guide,* which made recommendations on how to mark legacy items. It provides technical information on how to mark legacy items and is derived from the *DOD Standard Practice Identification Marking of U.S. Military Property*, MIL-STD-130N w/Change 1, dated 16 November 2012. MIL-STD-130N provides the benchmarks for product engineers to develop specific IUID marking requisites for ISO.

B. INTRUSIVE VERSUS NONINTRUSIVE IUID MARKINGS

Intrusive and nonintrusive markings are two ways that an IUID data matrix symbol can be applied to an item (Deputy Assistant Secretary of the Navy, Expeditionary Programs and Logistics Management, 2011). An intrusive marking method is one that removes or deforms the surface of the item that is being marked, such as dot peening, stamping, abrading, scribing, and etching. A nonintrusive marking method adds materials to the surface of the object being marked, such as stenciling, laser bonding, direct ink-jet, or a label and data plate (Deputy Assistant Secretary of the Navy, Expeditionary Programs and Logistics Management, 2011).

1. Decision Factors for Marking

When deciding what kind of mark an item should have, the following factors should be taken into consideration.

- Function.
- Available marking area.
- Material type.
- Color.
- Hardness.

- Surface roughness/finish.
- Surface thickness.
- Operating environment. (Deputy Assistant Secretary of the Navy, Expeditionary Programs and Logistics Management, 2011, 2)

The *DoN IUID Marking Guide* recommends that legacy items be marked with a nonintrusive marking method unless specifically approved by a competent quality assurance, safety, or engineering expert that is associated with item being marked. One of the reasons why a legacy item should only be marked with nonintrusive marking is that we do not want to compromise the metallurgy integrity of the item, if the item being marked is made of metal.

For example, if a steam engine room pipe, which operates at 700 pounds per square inch (psi), were to get an intrusive marking, then that pipe would now have a stress point that could lead to a major casualty. A warship may, at times, have to operate at a maximum engine bell during engineering drills or when conducting real-world combat operations. If the steam pipe is continuously operating at a maximum load, then the likelihood of that pipe rupturing, due to the stress fracture caused by an intrusive marking, is very high.

If it is deemed necessary that a legacy item must have an intrusive marking, then it will be necessary for a competent quality assurance, safety, and engineering officer to authorize the intrusive marking. One or a combination of the following safety measures must be taken into consideration when marking a legacy item with an intrusive method.

- Appropriate engineering drawings and specifications.
- Approved marking device settings.
- Depth measurements and microscopic evaluation equipment.
- On-site quality, safety, and engineering personnel to certify and monitor the marking procedure.
- Evaluation and disposition of markings that are improperly applied.
- Assessment of cumulative effects of removing and reapplying a marking. (Deputy Assistant Secretary of the Navy, Expeditionary Programs and Logistics Management, 2011, 2)

An example of when an intrusive method might be used on a legacy item instead of a nonintrusive method is the stabilized guide slope indicator (SGSI) located on the fantail of a Navy vessel. For example, while visiting the USS *Fort Worth* (LCS 3), the NSLC IUID technician expressed concern when applying a nonintrusive adhesive-bound IUID tag on the SGSI. If the label were to come off, it would become FOD and cause damage to the aircraft and gravely injure the aircraft crew.

Another reason why we would recommend placing an intrusive IUID marking on an SGSI is due to the environmental exposure that a nonintrusive metal will have that can degrade the IUID marking over time. For example, a laser-bounded or direct ink-jet marking can degrade over time due to ultraviolet sunlight and salt water exposure. A metal IUID data plate can also degrade by generating rust on the IUID marking caused by salt water exposure.

2. IUID Placement

There are several factors to consider when deciding where to place the IUID marking. According to the Deputy Assistant Secretary of the Navy of Expeditionary Programs and Logistics Management, IUD Marking Guide, the following are some of the determining factors.

- Protected areas.
- Flat surfaces.
- Areas that will make the mark readable while in service.
- Areas that will make the mark readable while stowed.
- If applicable, areas that will allow multiple markings.
- Areas that will not impede service members from performing maintenance. (Deputy Assistant Secretary of the Navy, Expeditionary Programs and Logistics Management, 2011, 3)

Unless authorized by a competent authority, IUID markings/labels should not be placed in the following areas.

- Over air vents/intakes.
- Any pertinent information belonging to the item being marked.
- Windows, access ports, view ports or fastener holes.

- Seams that connect an item.
- Sealing items.
- Wearing Surfaces.
- Near or on high heat sources.
- Over lenses, optics and sensors.
- Surfaces with dimensional tolerance requirements.
- Items that require precise clean parts in a hermitically sealed packaging. (Deputy Assistant Secretary of the Navy, Expeditionary Programs and Logistics Management, 2011, 4)

3. Cell Size

The IUID cell size is very important in order to ensure the readability of the data matrix if it is ever damaged. If the IUID tag is ever damaged in a normal operating environment due to heat, salt water exposure, maintenance, or overhaul of the item, then it will be easier for the reader to reconstruct the data. Figure 8 best describes how the size of the IUID module matters when taking into consideration the environment in which the data matrix will be located.

Mild Environments	Moderate Environments	Harsh Environments
General office conditions where there are moderate temperatures and minor exposure to non-abrasive cleaning chemicals. Examples include office furniture, calculators, computers, reproduction machines, and so forth.	Indoor or general outdoor use. Parts are exposed to some chemicals and abrasives, moderate cleaning and exposure to outdoor environments in temperate regions. Examples are in-plant fixed assets, embedded parts, internal air, sea or ground vehicle components (less engines), and so forth.	Harsh indoor/outdoor conditions; long-term exposure to salt air, caustics; extreme temperature variations; exposure to chemicals, including petroleum products; frequent cleaning and exposure to autoclaves, chemicals, or abrasives. Examples are external aircraft components, engine parts other than internal combustion engine components, refinery equipment, work-in-process manufacturing, and tools
Minimum suggested cell size 0.008-inch required for successful reading.	Minimum suggested cell size 0.010 inch (0.254 mm).	Minimum suggested cell size 0.020 inch (0.508 mm) or larger.
Minor damage can render a mark unreadable.	Error correction can reconstruct symbol.	Less error correction needed.

Figure 8. Minimum Cell Sizes for Expected-Use Environments (from DoN, 2011).

In a shipboard setting, we assess a mild environment setting to be equipment that is located in an office such as staterooms or the ship's administrative office. An example of a moderate environment will be places on the ship, like the Combat Information Center (CIC), the mess decks, and the bridge, where service members continuously clean. A harsh environment is considered to be an indoor/outdoor environment that is continuously exposed to the environment such as salt water, ultra-violet (UV) rays caused by sunlight, and extreme temperatures, such as an engine room (Deputy Assistant Secretary of the Navy, Expeditionary Programs and Logistics Management, 2011).

4. Contrast

The minimum acceptable color contrast between the equipment being tagged at the data matrix is 20 percent. If the equipment is dark, then the IUID data matrix must be light enough for the data reader to be able to decode the tag. Figure 9 best describes the minimum recommended contrast difference between the equipment and the IUID data matrix.

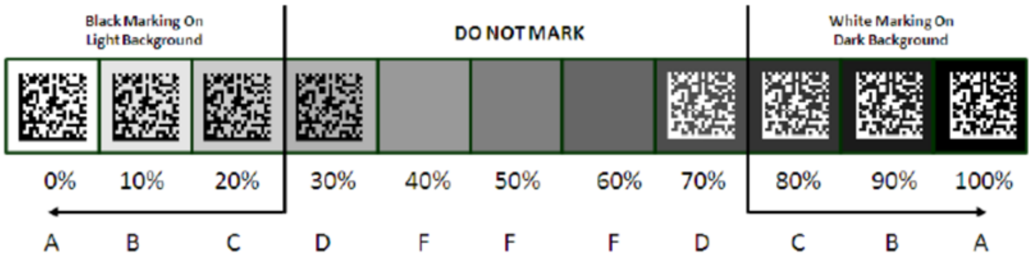

Figure 9. Mark Quality Verification Grades (from DoN, 2011).

There is also a quiet zone around the ECC200 data matrix that must be left unmarked in order for the scanner to successfully read the symbol (Deputy Assistant Secretary of the Navy, Expeditionary Programs and Logistics Management, 2011). It is recommended that an extra 10 percent of the lengthiest side of the symbol be extended around the data matrix. For equipment that has a 20 percent or more substrate on the gray scale, we recommend placing an IUID sticker with a white background and a black data matrix. No matter how dark or light the surface of the item is, with the quiet zone around the data matrix the reader will be able to decode the information on the IUID symbol.

IV. IUID ANALYSIS AND IMPLEMENTATION

A. INTRODUCTION

This chapter includes a detailed look at the following:

- current marking process used by NSLC,
- multiple other marking methods that would satisfy the Navy's requirements
- a cost benefit analysis

Our essential point is to guide NSLC staff in deciding the favored marking methodology for their needs.

We will establish our recommendations for the IUID marking process in the next chapter by conducting our analysis of each marking method and process based on the following criteria. First, how much time does it take each marking process from start to finish? Second, what are the costs associated with each marking process. These will be the actual marking process costs, which are in fiscal year (FY) 2015 dollars, unless stated differently. The third evaluation criteria is whether the marking method is feasible, while considering the operational status of the equipment and any need to compromise either the system configuration or the part itself by an intrusive marking method.

Our analysis was conducted based on some assumptions as a standard. The process requirements entail, but are not restricted to, the ensuing and are based on estimated times from the current sticker type label process and researched label printing times. All of the following analyzed process flows assume that the IUID technician is familiar with the required marking process and has been properly trained to carry out the marking process as designed. It is also assumed that the IUID technician is familiar with the site layout and shipboard space, compartment, equipment, and part markings, as this type of environment is not standard in the civilian business environment. This was also based on parts that do not require extra work to be done on them or to be physically removed from the system to be marked, such as a valve being tagged out on a ship to be removed, or lagging, which requires removal or paint, which needs to be scrapped, or any sanding that is required in order for the marking processes to happen. Another assumption is that with each detailed process described, we are not taking into consideration any additional time for technical difficulties beyond those described in a faulty or unreadable label or 2D matrix. This extra effort might include replacing ink, if required, or batteries that are not charged, or disposable batteries that are dead, or faults in printers or readers, or power outages, or anything of this nature. These are factors that are far too unpredictable to put a time or value to for the purposes of this project.

B. CURRENT IUID TAGGING PROCESS ONBOARD LCS 3 USS FORT WORTH

On July 31, 2014, we conducted a site visit aboard LCS 3 USS *Fort Worth* in order to observe the current IUID tagging process of legacy items. The eight to 10 contractors (IUID technicians) tasked with tagging the equipment on LCS 3 were assigned by NSLC. The contractors were using an S6700 series (DS6700-SR2000) Reader/Scanner made by Symbol Tech in New York, a Panasonic CF-19AHUAX1M Toughbook (laptop), and the IUID labels made by Metal Craft.

During the IUID technicians' time aboard LCS 3 there would be between eight and 10 people tagging the roughly 22,000 pieces of equipment around the ship that met the criteria to have an IUID tag. Each process step, as outlined in the process flow Diagram 1, takes between one to two minutes, on average, to complete. The legacy items do not need to be removed from their current systems in order to tag them, nor does this labeling process compromise the integrity of the parts/equipment. The IUID tagging process was done with the items in their current configuration.

The NSLC IUID technicians spent between six and eight hours a day, five days a week, tagging all of the 22,000 items aboard LCS 3 that met the criteria to have an IUID tag. Over a span of three years, the NSLC IUID technicians were able to tag approximately 75 percent of the items required to be tagged due to the ship's operational schedule. The IUID data that is accumulated by the IUID technicians is then uploaded into the IUID registry managed by the Naval Surface Warfare Center (NSWC) in Corona, California. There is no set amount of information that needs to be accumulated before it is sent to NSWC.

1. Current NSLC LCS 3 Label Process Outline

Diagram 1 in Figure 10 outlines the process flow NSLC technicians used onboard LCS 3 over the past three years with the goal of identifying, labeling, and registering the nearly 22,000 individual items identified as meeting the criteria for requiring IUID tagging.

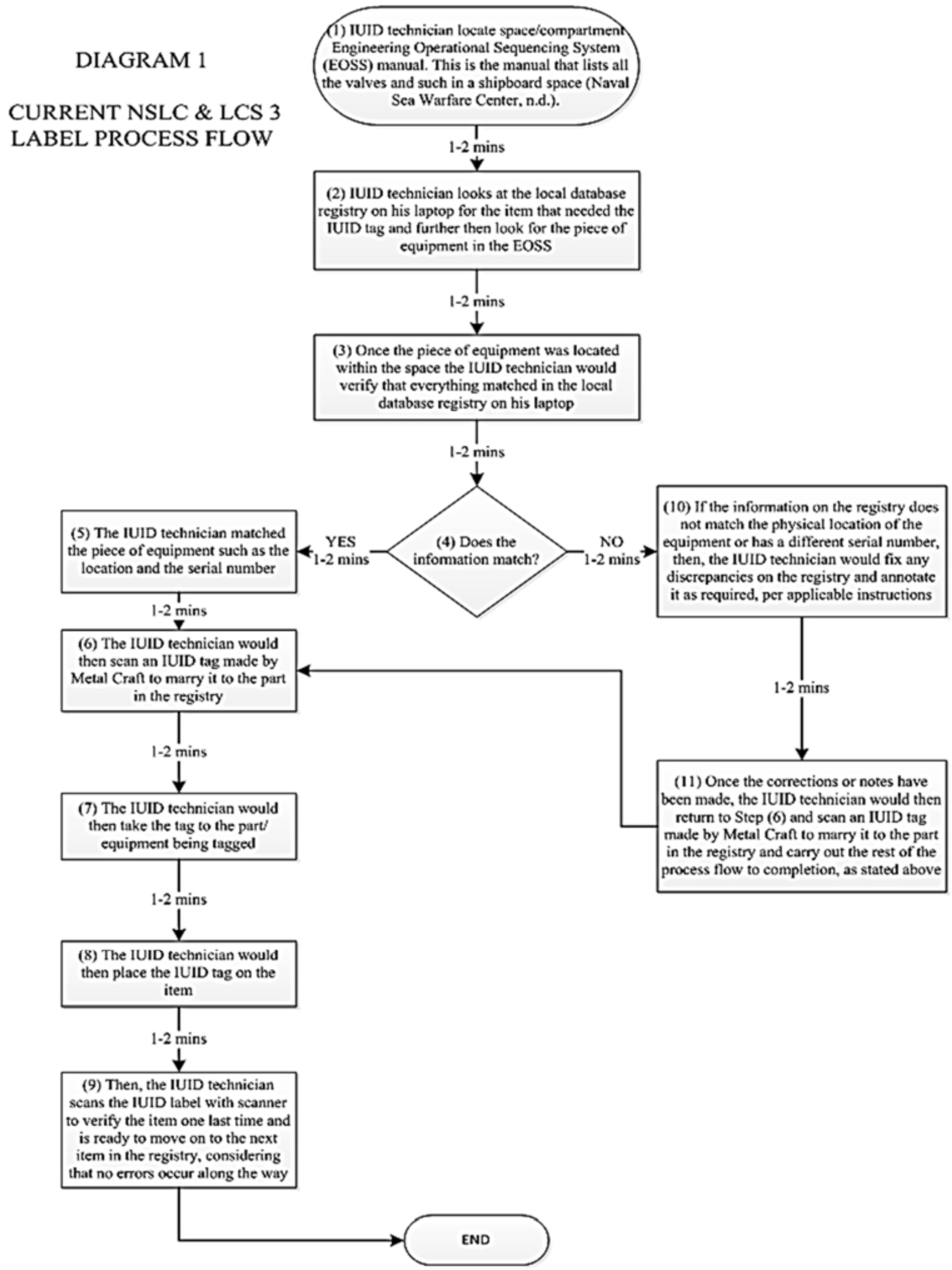

Figure 10. Current NSLC and LCS 3 Label Process Flow.

a. Benefits

NSLC has hired the necessary personnel, mostly retired Navy, to conduct the current tagging process. These contractors have the necessary knowledge to find the equipment throughout a Navy vessel. The current process was implemented several years ago and the contractors are very familiar with the procedures and steps to tag an item. NSLC has also invested in the Tough Books, scanners, labels, registry, and training needed to execute the labeling process.

b. Drawbacks

The major drawbacks of this marking technique would be in the quality of the adhesive and its possible lack of longevity for the life of the parts/equipment being marked. Furthermore, the ease with which this label could become compromised from various elements such as cold, heat, steam, liquids, chemicals, or by personnel peeling the labels off is also a concern for the current labelling process. While doing a site visit aboard LCS 3, we determined that some of the sailors did not know the purpose of the IUID labels. Contractors were also having a hard time trying to label equipment that was in secure spaces, such as the CIC. Contractors would have to have the ship’s personnel escort them into a secure space. Due to the limited amount of personnel on an LCS platform, it can impact the ship’s personnel operational tempo, especially while a ship is going through a training cycle. Mission modules are used on LCS platforms and having the ability to track all the modules through the Navy can be challenging, because they belong to different warfare commands and are only onboard during a specific mission.

c. Cost Analysis

The main benefit of this process is that it is substantially less expensive than most of the other marking techniques that we will examine. When the complete cost of a label is looked at, we can see that there is the initial infrastructure cost involved, i.e., a one-time buy of gear, for example, the printer, the reader/scanner, and the laptop for the database management. There are other costs as well, which are recurring, such as the paper to print the labels on, the ink to utilize in the printer, and the self-adhesive clear laminate paper.

C. OTHER MARKING METHODS THAT MIGHT SATISFY THE NAVY'S REQUIREMENT

While it may serve the user well to utilize already established marking processes and procedures, it would still be beneficial to conduct a survey to identify the most appropriate materials and methods to use. There continue to be advances in new technologies, which allow for more marking methods, although one should not overlook the current technologies, which have been further perfected since their inception (Deputy Assistant Secretary of the Navy, Expeditionary Programs and Logistics Management, 2011). MIL-STD-130N w/CHANGE 1 details all IUID requirements and is the solitary IUID marking authority (Department of Defense, 2012).

The following sections will first provide an overview of each of the three primary methods of marking an item with an IUID Data Matrix; second, provide a detailed description of the process involved, when available, and/or the overall benefits and drawbacks with each technique within the three methods; and, finally, provide the cost-to-benefit analysis for each technique, as described.

The three primary methods of marking an item with an IUID data matrix are label printing, data plates, and direct part marking (DPM). Typically, all item-marking techniques used by manufacturers are compatible with one or more of these techniques. Figure 11 shows the generalized label process.

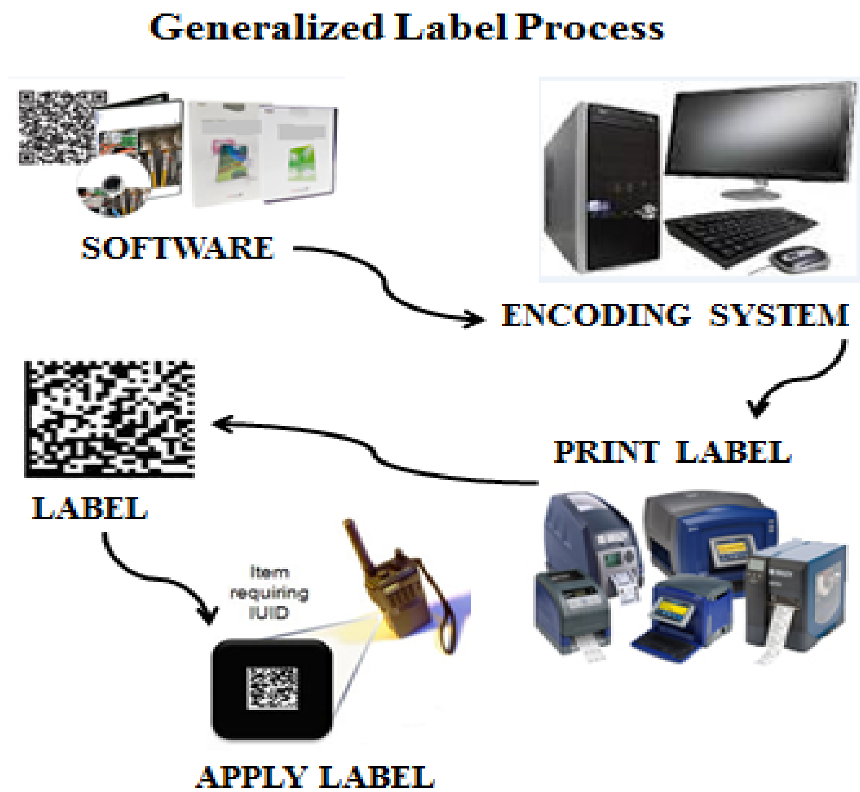

Figure 11. Generalized Label Process (after UID Forum, 2010).

1. Labels

A specific method of marking should not be considered to be weak, as they all serve a purpose, albeit labels are thought of as not being as durable a marking practice as some others. If there is no requirement for the form, fit, or function to be altered, and further, if there is no requirement for updates to drawings, then the user should first consider utilizing label methods (Office of the Secretary of Defense, n.d.). Post-It-Notes®, for example, are undoubtedly one of the least durable label types, albeit the welding of steel plate should be considered among the most permanent. Using labels, which are available in a variety of materials and can be applied using many different methods, is often the cheapest and most convenient marking method available (Deputy Assistant Secretary of the Navy, Expeditionary Programs and Logistics Management, 2011). Typical label markings include ink-jet labels, as shown in Figure 12.

Figure 12. Ink-Jet Label (Sticker) (from Roemer Industries, 2014).

- **Cost:** Typically the least expensive method of marking.
- **Time:** Quickest progress towards compliance.
- **Benefit:** Work for majority of situations, produce high contrast marks, have low impact when "goofed-up," requires very little training for this method.
- **Negatives:** Can be destroyed by temperature extremes, can fall off/be removed, are soft (abrasion problems), vulnerable to certain chemicals & UV light.

2. Detailed (Paper, Polyester, and Metal Foil) Labeling Processes

Diagram 2, Figure 13, outlines the labeling process for paper, polyester, and metal foil labels that could be used by NSLC technicians to label items identified as meeting the criteria for requiring IUID tagging. This process is similar to the process used onboard LCS 3, with the primary difference being in the label material used.

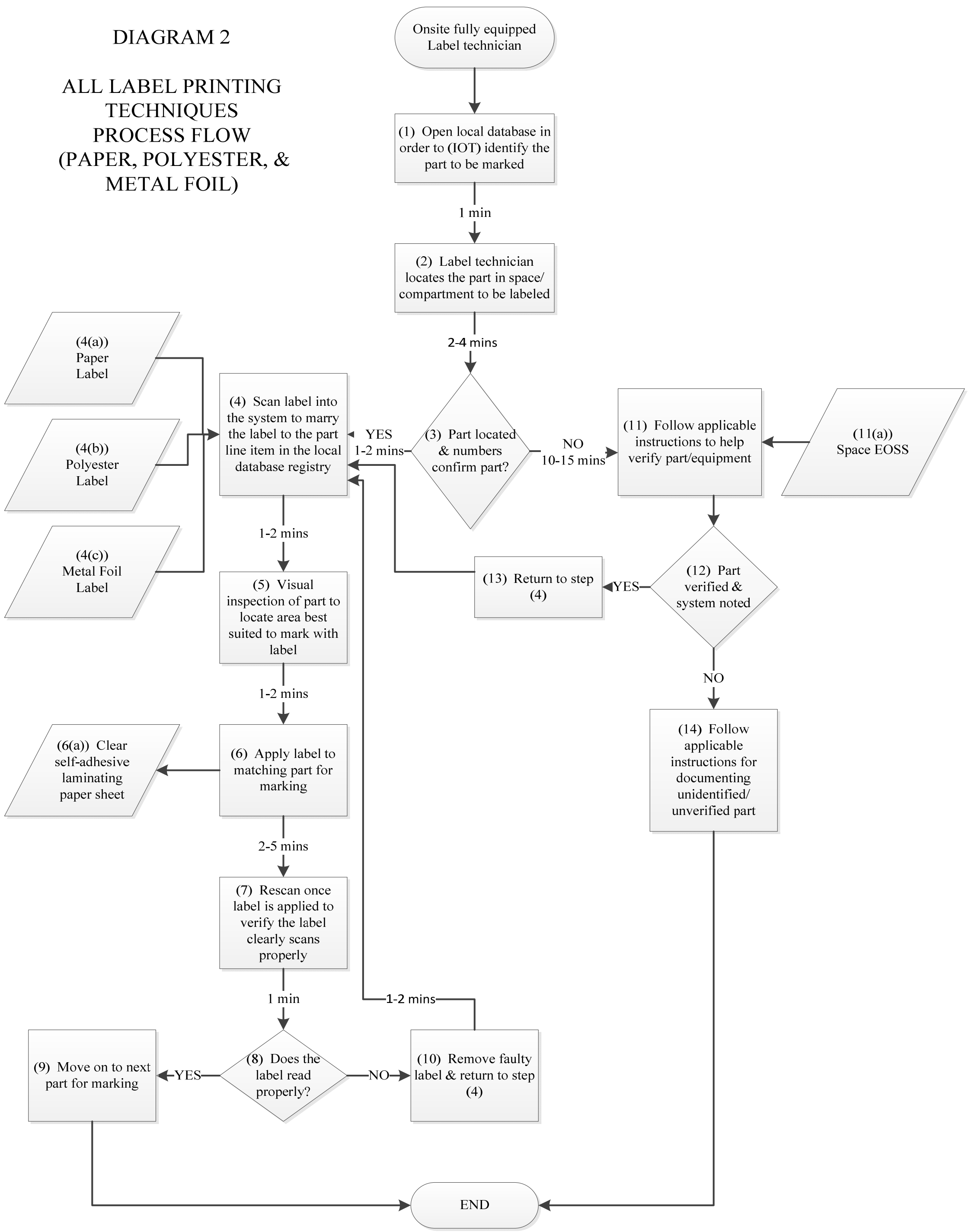

Figure 13. Combined Process Flow Diagram for all IUID label techniques.

a. Benefits (paper)

The label printing (paper) IUID marking technique can take an average low end of nine minutes to an average high end of 32+ minutes to complete a part being marked on site, given that all of the required materials are on site and ready for use. The only extra effort necessary might be the need to replenish ink for a printer when using an individual label printer or should there be some unexpected technical issue with a reader/scanner, laptop, printer, software, or the database itself, which we are not evaluating in this project.

b. Drawbacks (paper)

The major drawbacks of this marking technique would be in the quality of the material and its lack of possible longevity for the life of the parts/equipment being marked, and, further, the ease with which this label could become compromised from various elements such as cold, heat and steam, liquids or chemicals, or other types of elements that could very easily destroy this type of label. Further during the process is the likely chance of needing to rework label items with possible human error in allowing for air bubbles to gather between the laminate and the paper label, similar to a bad automobile window tinting job, where the reader/scanner would fail to be able to read the 2D matrix because of the bubbling or other particles being in the way. With this type of rework, the process time can be substantially increased by double the amount of time or more, depending on how many times an IUID technician would need to rework a label marking during any given work period.

c. Cost Analysis (paper)

The main benefit of this process is that it is substantially less expensive than most of the other marking techniques we will examine. When the complete cost of a label is looked at, we can see that there is the initial infrastructure cost involved, a one-time buy of gear (e.g., such as the printer, the reader/scanner, and the laptop for the database management), which will be further addressed later in this project. The other costs involved, which are recurring costs, are the paper to print the labels on, the ink to utilize in the printer, and the self-adhesive, clear, laminate paper.

d. Benefits (polyester)

The label printing (polyester) IUID marking technique can take an average low end of eight minutes to a high end of 29+ minutes to complete labeling a part being marked on site, given that all of the required materials are on site and ready for use. This is a quicker overall technique from the paper labels, as the need to handle the laminating sheets becomes a bit of extra work when compared to these self-adhesive labels. An additional benefit is that these labels are thin and malleable, obtainable in thicknesses of 0.002” thru 0.008” and already have adhesive backing. They are optimal for caustic surroundings and the graphics can be printed on the subsurface or protected with an over laminate (Technigraphics, n.d.).

e. Drawbacks (polyester)

The major drawback of this marking technique is that they are less durable than the metal foil, which lends to possible failure before the life of the parts/equipment being marked, and the ease with which this label could become compromised from various elements such as cold, heat and steam, liquids or chemicals, or other types of elements that could destroy this type of label (Technigraphics, n.d.).

f. Cost Analysis (polyester)

The main benefit of this process is that it is less expensive than metal foil and most of the other marking techniques that we will examine. When the complete cost of a label is looked at, we can see that there is the initial infrastructure cost involved, a one-time buy of gear (e.g., such as the printer, the reader/scanner, the laptop for the database management, and software), which will be further addressed later in this project. The other costs involved, which are recurring costs, are the blank label sheets to print the labels on and the ink to utilize in the printer.

g. Benefits (metal foil)

The label printing (metal foil) IUID marking technique is very similar to the Polyester Labels and can take an average low end of eight minutes to a high end of 29 + minutes to complete the labeling of a part being marked on site, given that all of the required materials are on site and ready for use. Again, this is a quicker overall technique from the Paper labels, as the need to handle the laminating sheets becomes a bit of extra work when compared to these self-adhesive labels. An additional benefit is that these labels come in thicknesses of 0.003” to 0.005” and meet the requirements of MIL-DTL-15024F (Department of Defense, 1997). These labels provide higher contrast and exemplary resolution, while combining the resolve of a dense aluminum nameplate, yet they are flexible and conform to a surface similarly to a label. They have an outdoor vulnerability lifespan upwards of 20 years and withstand severe environments, chemicals, scrapes, solvents, and varying temperatures (–40 Fahrenheit (F) to +450F). As a tamper-evident component, this label also provides the security of fracturing when attempting to remove it from its surface after bonding (Technigraphics, n.d.).

h. Drawbacks (metal foil)

The major drawbacks of this marking technique would be in the lack of possible longevity for the life of the parts/equipment being marked. Furthermore, the ease with which this label could become compromised from various elements such as cold, heat and steam, liquids or chemicals, or other types of elements could very easily destroy this type of label. Identifying any one best metal foil label for all marking applications may prove difficult, as there are multiple strengths, thicknesses, and adhesive-backed types of labels in this category from which to choose, along with multitudes of vendors to provide such labels.

i. Cost Analysis (metal foil)

Again, this technique being very similar to the previous polyester label shows that the main benefit of this process is that it is less expensive than most of the other marking techniques we will examine. When the complete cost of a label is looked at, we can see that there is the initial infrastructure cost involved, a one-time buy of gear (e.g., such as the printer, the reader/scanner, the laptop for the database management, and software), which will be further addressed later in this project. The other costs involved, which are recurring costs, are the blank label sheets to print the labels on and the ink to utilize in the printer.

The next section, data plates, starts with Figure 14, which shows a simplified data plate inscription process.

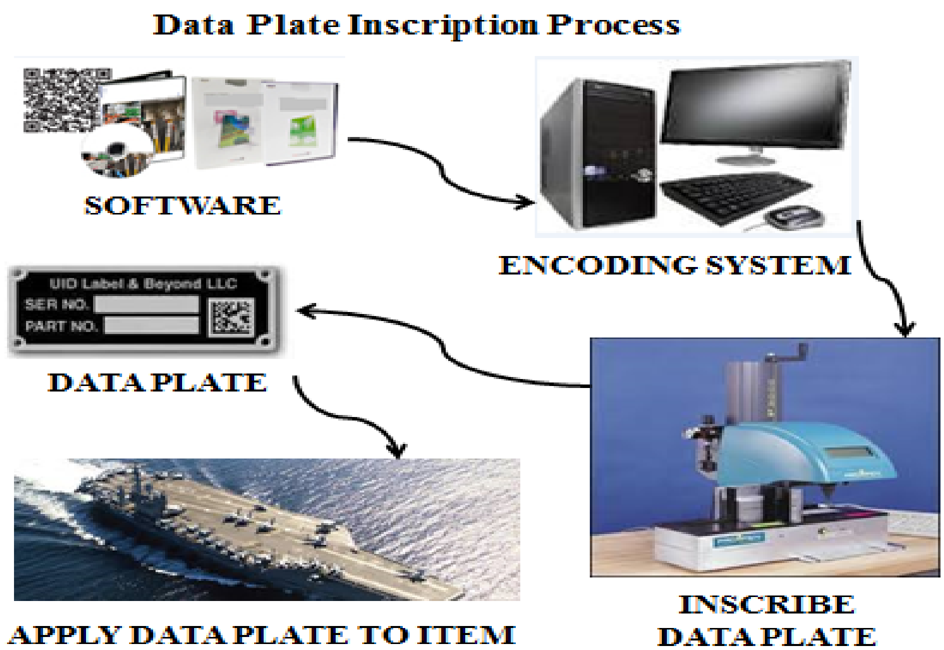

Figure 14. Data Plate Inscription Process (after UID Forum, 2010).

3. Data Plates

Data Plates can be created in-house, using expensive equipment, or ordered from an external source. There is an inherent risk, for the DOD source, when ordering preprinted data plates. The DOD source must ensure very stiff quality production processes are in place in order to reduce the risk of incorrectly applying the plates or possibly incorrectly recording UID numbers. They utilize a plastic or metal plate that can be attached with rivets, screws, industrial-strength adhesives, and even zip-tie-type hangers through the holes, as shown in Figure 15. Data plates can be used if there is no requirement for the form, fit, or function to be altered, and further, if there is no requirement for updates to drawings, then the user should first consider utilizing label methods (Office of the Secretary of Defense, n.d.).

Figure 15. Metal Data Plate (from A2B Tracking, 2013).

- **Cost:** Typically more expensive method than labeling.
- **Time:** More time intensive than labeling in both material prep and application.
- **Benefit:** Produce high contrast marks, have low impact when "goofed-up," much more durable than labels for longevity and variety of environments they can be used in. Cannot easily be destroyed by temperature extremes, do not typically fall-off, typically require deliberate removal.
- **Negatives:** More rigid in construct and hence may not effectively be applied to oddly shaped and sized items, requires moderate training for proficiency of this method.

4. Plastic Data Plate

The following section on plastic data plates provides information on the benefits, drawbacks, costs analysis, and ideal application. Again, plastic data plates do provide some flexibility with a variety of different plastics allowing for versatility of use.

a. Benefits

Data plates come in multiple variants of plastics, which make for increased longevity and allow them to handle risk of contact with certain chemicals and alternate hazards. With multiple application techniques, data plates can be attached with screws, rivets, or various other fasteners, allowing them to be utilized in situations not conducive to adhesives.

b. Drawbacks

Not all environments or situations are conducive for using adhesives to apply data plates, which makes the possible loss of a data plate more likely, depending on the environment of the equipment being marked. Data plates can possibly increase the radar visibility of equipment or items after plating. This can possibly cause a safety and security issue by allowing for unintended effects of increased radar visibility.

c. Cost Analysis

Producing data plates can be moderately expensive, according to Zebra Technologies, "ranging from about $5,000 for a low-volume, plastic plate machine to $20,000 for laser markers. Data plates also cost approximately 10 times as much as labels." As previously mentioned, alternate methods of attaching the data plates tend to increase costs through time and labor (Zebra Technologies, 2005, 2).

d. Ideal Application

The plastic data plates, also known as a polycarbonate or thermoplastic data plate are designed to hold up against extreme environmental conditions. If the users aim is to subject it's items or equipment to severe varying temperature ranges or in the case of NSLC, if the items or equipment are meant to be viable in seagoing environments onboard ships, then plastic data plates could be an option if the item has the space available to place the data plate and, ultimately, depends on the method in which the plate would need to be attached.

5. Metal Data Plates

The following section on metal data plates provides information on the benefits, drawbacks, costs analysis, and ideal application. Metal data plates provide some flexibility with a variety of different metals and durability allowing for versatility of use.

a. Benefits

Data plates come in multiple variants of metal, which make for increased longevity and allow them to handle risk of contact with certain chemicals and alternate hazards. With multiple application techniques, data plates can be attached with screws, rivets, or various other fasteners, allowing them to be utilized in situations not conducive to adhesives.

b. Drawbacks

Not all environments or situations are conducive for using adhesives to apply data plates, which makes the possible loss of a data plate more likely, depending on the environment of the equipment being marked. Metal data plates can possibly increase the radar visibility of equipment or items after plating. This can possibly cause a safety and security issue by allowing for unintended effects of increased radar visibility.

c. Cost Analysis

Producing data plates can be moderately expensive, according to Zebra Technologies, “ranging from about $5,000 for a low-volume, plastic plate machine to $20,000 for laser markers. Data plates also cost approximately 10 times as much as labels.” As previously mentioned, alternate methods of attaching the data plates tend to increase costs through time and labor (Zebra Technologies, 2005, 2).

d. Ideal Application

Aluminum data plates can handle being exposed to severe weather and temperature variations, UV rays, fungus, sea water spray, and certain acids. Anodizing the aluminum data plate increases the lifespan. According to Data Graphics, Inc., “A data plate made of aluminum is best used for rating plates, dials and scales, templates, instructional tags, and corporate identity and serial number plates” (Data Graphics, 2008, 1).

The next section, direct part marking (DPM), starts with Figure 16, which shows a simplified DPM Process.

Figure 16. DPM Process (after UID Forum, 2010).

6. Direct Part Marking

The DPM process stamps or etches directly to the unit to be marked. Composition plays a key role in the ideal process utilized to mark an item using these methods. DPM equipment is able to produce the 2D barcode more efficiently, hence the reason for the 2D data matrix being chosen as the UID standard symbol (Zebra Technologies, 2005).

In general, DPM tends to last longer and at the same time is also the most risky option, since they can damage the structure of the material being marked; but, they can be used if the alternative of adding material to the item is unacceptable (Deputy Assistant Secretary of the Navy, Expeditionary Programs and Logistics Management, 2011). DPM embeds the marking directly into the item, where it typically remains for the item's lifespan. Given that this method has the potential to adversely affect the item's structural integrity, the exact method chosen must be carefully considered with regard to the item's structural tolerances and composition. DPM should only be used when approved by a competent quality assurance or safety engineer that is associated with the specific item being marked. Engineering analysis is inherent with DPM as compared to labeling requiring very little technical analysis, if any. While the faster laser etching is preferred over dot peen or electro chemical etch, the drawbacks to any DPM method are possible errors with permanent damage and compromise of the item (Secretary of the Air Force, 2008).

According to Stephen Spence, a world-class engraver with more than 20 years in the trade who has written regularly for engraving trade magazines and has tested numerous different engraving systems and further owns his own engraving company, "Most people agree that the vast majority of UID nameplates (and a lot of DPM, too) will be done with some type of laser." Apparently, numerous manufacturers are installing advanced laser systems on their production lines in order to directly mark parts as part of the manufacturing. While there are plenty of items that will be marked using this method, undoubtedly there will be numerous parts, which may not, since parts travel along the production line in an identical way and laser DPM could be close to impossible to use. Stephen Spence wrote, "The difference between an yttrium aluminum garnet (YAG) laser and the carbon dioxide (CO2) laser is akin to the difference between a hacksaw and a woodworker's saw. They are both basically the same thing, but they each work best on a select number of materials" (Spence, 2005, 2).

a. Cost

This method is typically more expensive method than labeling or data plates.

b. Time

This method is more time-intensive than labeling or data plate.

c. Benefit

Produce high contrast marks, considered to be the most durable method, not easily destroyed by temperature extremes, permanent marking for life of the item. The strengths of the 2D barcodes created by DPM are its vast efficiency with space and its longevity. When severe environments are a concern, DPM should be highly considered since the 2D barcode physically bonds with and becomes part of the equipment. DPM typically only requires a one-step operation to create the data matrix (Zebra Technologies, 2005).

d. Negatives

Have high impact when “goofed-up” may adversely affect the structural integrity or composition of the item, and requires highly trained accuracy and skill to conduct. With the marking being done directly onto the part or item, this can necessitate engineering analysis to ensure the DPM process does not instead damage the integrity or composition of the item being marked. When available, previously documented results of engineering analysis should be utilized (Office of the Secretary of Defense, n.d.). The DPM process can be undesirably slow. Although there are no supplies to contend with, both waste, and the possibility of incorrectly applying a symbol can create an undesired expense. Due to these boundaries, in addition to the higher cost of equipment, DPM should be considered on a selective case by case basis and further typically as a last resort (Zebra Technologies, 2005). DPM drawbacks outweigh the benefits and, for that reason, we feel that DPM is not a viable option for legacy items. DPM should only be considered when non-legacy items are being marked by the manufacturer or a knowledgeable authority that is associated with the piece of equipment. Some of the typical DPM methods are:

7. Direct Ink-Jet

This is the practice of using circular dots, small enough in size, sprayed precisely on the exterior of a part.

a. Benefits

A high contrast 2D data matrix can be achieved, dependent on the surface type it is added to. Typically, the ink density is less than 0.001.” With this being an additive process, removal is relatively easy and avoids damage to any parts if an error is caught prior to the curing of the ink. If the situation called for it, a portable ink-jet printing system could be brought onsite for larger items, while small- or medium-sized items could be delivered to the system location for marking (JTEC Corporation, 2004). Ink-jet printing can quickly and easily be read when given good and high contrast.

b. Drawbacks

While some permanent inks exist, ink-jet is not typically considered to be a permanent marking method by industry standards. Maintenance should be conducted routinely to ensure proper working order of the jets and primarily to prevent clogging. According to the JTEC Corporation,

> In order to achieve marking permanency with the ink selected for use, a curing process (UV or thermal) may be required. Chemical waste is generated by an ink-jet process during the head cleaning, printer maintenance, or general part-cleaning process. Not all ink-jet printers are the same. Some require more maintenance than others; thus, printer selection is more difficult. (2004, 1)

The marking quality depends on the cleanliness of the exterior being marked and can be very difficult to read if the contrast is poor (Moss, n.d.).

c. Cost Analysis

Low entry cost. JTEC Corporation (2004) says that "Ink-jet marking systems range from \$8,500 to over \$100,000, depending on system configuration." Ink-jet printing has a high cost for consumables.

d. Ideal Application

This method has a wide range of applications, as it is an additive method that can be applied to exterior packaging or directly to a multitude of different surfaces, including curved or flexible surfaces, considering that the ink is allowed to cure before being moved. Again, this is not a method that is considered by most to be a true, permanent mark.

8. Dot Peen

According to Microscan Systems, Inc., (2010) "Dot Peen is a percussive marking method, using changes in depth to create the contrast between the light and dark elements of the symbol," as shown in Figure 17. Further writing, "Dot peen is recommended for applications where the symbol must last the entire life cycle of the part. Suitable substrates for dot peen marking must have some hardness so that material memory does not return the surface to its original condition" (Microscan Systems, Inc., 2010, 2). As far as the UID industry is concerned, dot peen is in its infancy. Stephen Spence (2005) writes that "Dot peen utilizes pneumatic or electric-controlled marking heads which 'push' a needle or stylus to impact or indent the metal to form a dot. Through repeated 'hammering' of the stylus against the materials' substrate, you can achieve either a data matrix (with one dot per cell location) or you can achieve a series of closely spaced dots which form characters, numbers, and other symbols in a way that reminds one of a dot matrix printer" (2). Dot peen machinery are highly advanced and computer driven, although similar to a rotary engraver, with the difference being that the marking tips move upwards and downwards instead. Stephen Spence (2005, 2) likened this process to the "old dot matrix printers, which had either nine or 24 pins, the text generated by the nine-pin head was readable, but nothing like the printers we have today. The 24-pin printers could produce images surprisingly close to today's ink-jets. The image was created by the pins striking a ribbon and thus transferring ink from the ribbon to a sheet of paper." There is no need for a ribbon or ink, as the symbol is created by a series of dots placed at a specified depth into a surface, typically metal, but can be used on non-metal, particularly plastics, as well (Spence, 2005, 2). This method should not be used in instances where:

Figure 17. Dot Peening Example (from Spence, 2005).

- Materials are less than 0.02 in. thick.
- Surfaces that are electrical discharge machined (EDM), grit blasted, machined, and shot peened between 8 and 250 micro-inches (0.0002 and 0.0063 mm) using a single dot per cell.

- Cast surfaces between 8 and 120 micro-inches (0.0002 and 0.003 mm) using a single dot per data cell, multi-layer fabric reinforced laminates, non-metallic materials that chip, shatter, or retain shape after impact.
- Real estate that is within a distance of four times the material depth from any edge, weld, or forming radius, or high pressure system components.
- Metals hardened above HRC 54 or highly stressed parts without engineering approval. (Secretary of the Air Force, 2008, 2–11).

a. Benefits

Dot peen machines are capable of being used on many metal types, and are moderately fast, usually done marking in under a minute, while capable of producing high contrast readable text readable with the human eye. This method is ideal for 2D data matrix, numbers, and text.

b. Drawbacks

While not normal, but depending upon the metal being marked, there can be some deforming which takes place. Due to this, it is possible that the symbol or 2D matrix may be unreadable.

c. Cost Analysis

According to Stephen Spence (2005), "The machines range from under $1,000 to many thousands of dollars for a fully automated version. The difference in the machine cost varies with several factors such as the number of pins in the marking head, working range, number of axes, etc." (3).

d. Ideal Application

This method is ideal for marking a broad spectrum of materials, ranging from steel too softer plastics.

9. Electro-Chemical Etching

Low-voltage is used in this marking technique by passing electric current to the surface of the part via a stencil. That said, this method requires an electrically conductive metal surface in order to work. Electro-chemical etching (ECE) will not harm the composition or structure of the part, making this a great method for use on finer or thin-walled surfaces and parts.

a. Benefits

ECE is very fast, costs less than other methods, and is a true DPM method but avoids altering a materials microstructure or weakening the material in any way. Great for thin walled items, since this method attains a depth range from 0.0001” up to 0.010.” It is environmentally friendly and will not harm users.

b. Drawbacks

The Microscan Corporation (2005) says that “In order for this method to work, the part must have a conductive metal surface. This method will not work for anodized, powder-coated or non-conductive coatings. Since ECE is a more involved process than other methods, it is not suited for highly automated applications and is commonly used for small product runs” (1).

c. Cost Analysis

Speed of marking as a benefit of ECE. It is also lower cost than other methods and very reliable means of permanently marking an electrically conductive materials surface.

d. Ideal Application

Alloys, metals, and plated products, too numerous to mention are all able to be marked using this method. Nuclear reactor components, aircraft parts, ball bearings, medical instruments, and tools are some of the more common items to be marked with this method.

10. Engraving/Milling

This method of marking utilizes a computer-guided, diamond drag or carbide-tipped machine to imprint the data matrix into the surface of the part or item to be marked. As displayed in Figure 18, managing the dwell time, air pressure, and adjusting the cutter depth, the mark is able to be applied with high contrast clarity, although the marks readability can be enhanced by filling in the recessed mark with materials of contrasting colors (Secretary of the Air Force, 2008).

Figure 18. Engraving/Milling (from DATRON, 2014).

a. *Benefits*

Stephen Spence (2005) states: "When using a rotary engraver to make labels using painted metal, the contrast can be very high and, depending on the hardness of the paint, the mark might be extremely durable" (2).

b. *Drawbacks*

The primary drawback to utilizing a rotary engraving method for UID must be getting the matrix into the computer system. Currently there are few engraving systems with open architecture, like Corel DRAW[1] and Adobe Illustrator,[2] to interface with, allow for easier uploading of required design software, and until more system are upgraded or further new designs created, this method will continue to be a far less attractive means of UID marking (Spence, 2005). Some of the more challenging task with this method is the limits with shape, size, and being able to restrain the item for marking. This method may cause possible tearing instead of cutting, hence leaving behind an unreadable matrix depending on how dense or soft the surface being marked is. Further, when a surface is too smooth, the matrix may be difficult to read and not allow for back

[1] Corel Draw is a top-of-the-line graphics design software system that allows you to edit photos and design websites and layouts.

[2] Adobe Illustrator is a computer software program that is used to photo shop, build websites, and create sophisticated graphic designs.

filing of paints in order to intensify the readability. Lastly, this method currently is limited to large sized 2D matrix (Spence, 2005). According to Stephen Spence (2005), "Attempting to rotary engrave a 5 mm matrix would be extremely difficult, if not impossible. Doing a 20mm matrix might be quite acceptable, however, although many other methods would likely be faster than rotary engraving. One more issue with rotary engraving is speed, as this is not the best choice if speed of process is a factor" (2).

c. Cost Analysis

Engraving allows for lower start-up and mid-line operating costs offers low implementation and medium operating costs (Moss, n.d).

d. Ideal Application

Perfect for use on noncoated and coated metals; further uses are for plastics and stainless steel. Engraving transcends lasers when it comes to applying a 2D barcode to an uncoated metal surface (Spence, 2005). The Secretary of the Air Force (2008) says that "Engraving is a great marking method for glass, plastic, and phenolic, ferrous, and nonferrous metals" (2-14).

11. Laser Bonding

The Secretary of the Air Force (2008) states:

> This process involves the bonding of a material to the substrate surface using the heat generated by a neodymium-doped (Nd) YAG laser or equivalent. The materials used in this process are commercially available and generally consist of a glass grit powder or ground metal, oxides mixed with inorganic pigment, and a liquid carrier. The pigment can be painted or sprayed directly onto the surface to be marked, or transferred via pad printer, screen printer, or coating roller. (2-4)

Laser bonding could be utilized with CO2 lasers or commensurate, with ink foils to be used in less severe surroundings. This method does not actually cut into the surface, but rather binds a medium onto the external surface of the part for marking, and actually causes a mark which is raised from the surface. Necessary equipment for use in this marking method is the laser-bonding controls and a printer. The Secretary of the Air

Force (2008) commented that "Limited by coatings that are application-specific, it is generally limited to flat or slightly curved surfaces, and is restricted to materials thicker than 0.001" (2-4).

a. Benefits

> According to Moss, laser bonding overcomes the two most serious limitations of thermo-compression bonding, namely the need for high temperature and high pressure, which are known to cause damage to the device and affect its long-term reliability. (Moss, n.d., 4)

While there are numerous UID marking methods available, the CO2 laser may be considered one of the more common within this industry. With this, CO2 laser UID marking technology is essentially the weight-bearing method of choice. A CO2 system carries a power rating range from over 100 watts to as low as 5 watts and further allow the flexibility of markings as small as a few inches to four-by-five feet in height and width or even larger. Stephen Spence (2005) wrote:

> Another solution to engraving metals with CO2 lasers is adding what Universal Laser (Scottsdale, Arizona) calls a 'high power density focusing optic,' and Epilog (Golden, Colorado) calls 'radiance optics.'[3] These special lenses amplify the light beam as it passes through the lens assembly, causing it to intensify enough to mark some metals (by 'annealing,' which causes a color change in the metal). Although this is new and still somewhat expensive, it is certainly not out of the range of a semiserious user. (2)
>
> YAG lasers are known for their ability to affect metal. Many incorporate a mirror system called a galvanometer driven lens assembly. This makes these lasers unbelievably fast. The time required to mark a logo onto an ink pen might be less than one second while a raster controlled CO2 laser might take one minute. (Spence, 2005, 2)

b. Drawbacks

- Coatings are unique to the application, commonly restricted for minimally curved surfaces, and limited to external surfaces, while being further limited to material greater than 0.001" (0.025 mm) (Moss, n.d.).

[3] Universal laser and Epilog both have CO2 lasers that can produce smaller laser focal points that can precisely engrave in a very small area.

- There is one serious drawback with this method; it does not mark well on uncoated metals. "Print growth," is the term provided in the UID industry for a concern with marking UID using chemicals like CerMark or TherMark.[4] When flaring happens slightly on the item, it is due to using CO2; further, this flaring is not very visible to the naked eye and data matrix readers may be required (Spence, 2005).

c. *Cost Analysis*

- CO2 lasers that can be used for DPM or nameplates run the gamut from an $8,000 CO2 laser to a million-dollar, multi-lens laser capable of doing all kinds of things simultaneously (Spence, 2005).
- At one time, a small YAG laser would start at $125,000, but they have come down (as have the CO2 lasers) to the $40,000- and -up category, although there are some lasers that are even less expensive (Spence, 2005).

d. *Ideal Application*

- The CO2 laser DPM systems are ideal for quartz, substrates like wood, Plexiglas®, glass, fabrics, ceramics, and other organics; further, the CO2 laser frequency range makes it viable for marking acrylic, wood, leather, and most plastics. Some metals, such as steel, stainless steel, and chrome, can be marked by applying a chemical to the surface of the metal (Spence, 2005).
- YAG lasers are primarily intended for use in fine marking of heat-sensitive substrates such as (plastics, silicon, and metal foils), and further, where increased consistency is deemed necessary.

12. Laser Etching

Notwithstanding delivering a clean, improved-determination check on a mixture of substrates going from metal to plastics to glass, laser carving is likewise appropriate for robotized situations obliging high volumes. Since the top layer of the part's substrate is evacuated amid the drawing procedure, at times the negligible buildup that comes about may not be appropriate for certain clean-room operations. The sort of laser (CO2, yttrium orthovanadate [yvo4]) must coincide with the application and will influence cost extensively. While laser-carving gear has a higher entrance cost than numerous stamping techniques, there is no extra cost for consumables and support is negligible. Figures 19

[4] CerMark and Thermark are both laser-marking, bonding materials that help laser markings adhere permanently to the item.

and 20 provide an example of a laser etching and an example of the laser equipment for this method, respectively.

Figure 19. Laser Etching (from SIC Marking, 2014).

Figure 20. Laser Etching Machines (from Universal Laser Systems, 2014).

a. Benefits

By and large, laser drawing or checking is a subtractive procedure; material is evacuated to produce the imprint. Along these lines, laser imprints are perpetual imprints without obliging any curing methodology to attain checking permanency. High-determination print quality may be attainable and no possibly dangerous chemicals are needed. Laser-checking frameworks range from \$25,000 to over \$100,000, contingent upon framework design (JTEC Corporation, 2004).

CO2 lasers are the most widely recognized in our industry, by a long shot, and are incredible for stamping particular materials and will probably be the spine of the UID nameplate industry. These frameworks range from 5 watts to well in excess of 100 watts in force and offer imprinting choices in zones of as meager as an issue inches to four-by-five feet or bigger. The hotness of the laser then bonds the synthetic to the metal in such a manner, to the point that a processor is obliged to evacuate it. An alternate answer for imprinting metals with CO2 lasers is including what Universal Laser (Scottsdale, Arizona) calls a “high power thickness centering optic,” while Epilog (Golden, Colorado) calls theirs “brilliance optics.”[5] These uncommon lenses increase the light shaft as it passes through the viewpoint get together making it heighten enough to stamp a few metals (by “strengthening,” which causes a color change in the metal). In spite of the fact that this is new and still to a degree costly, it is unquestionably not out of the scope of a semi-genuine client (Spence, 2005).

YAG lasers are best known for their capacity to influence metal. Numerous consolidate a mirror framework called a galvanometer-driven lens get together. This makes these lasers staggeringly quick. The time needed to check a logo onto an ink pen may be short of one second; while a raster-controlled CO2 laser may take one moment (Spence, 2005).

b. Drawbacks

In general, ill-advised set-up can create scrap or oblige commenting in recently assigned territories. Set-up times for individual parts can change. Procurements for administrator security should likewise be joined into the checking procedure including fusing establishment inside controlled situations, far reaching administrator and upkeep work force preparing, and posting of laser cautioning signs. Laser-carving frameworks can be excessive when appropriately coordinated. For high-control laser frameworks, water chillers may be needed. Smolder extractors are prescribed so as to uproot laser flotsam and jetsam. Shameful set-up can result in potential imprint infiltration issues. The laser-carving methodology obliges an all the more exceptionally gifted administrator (JTEC Corporation, 2004).

[5] Universal Laser and Epilog both have CO2 lasers that can produce smaller laser focal points that can precisely engrave in a very small area.

CO2 lasers can be used to complete numerous tasks truly well, yet one thing they do not do well is imprint untreated metals. Worries about checking UIDs with chemicals, for example, CerMark or TherMark[6] is something many refer to as “print development.” This material, when reinforced utilizing CO2, has a tendency to energy somewhat. This flaring is not exceptionally evident to the bare eye, yet information framework perusers are more exact than our eyes. At the point when the dark imprint encroaches excessively over the empty (or white) cells, the imprint could get to be confused (Spence, 2005).

It is not recommended to use the YAG to engrave a wood plaque, as it yields disappointing results.

c. Cost Analysis

This DPM method runs the degree from a $8,000 CO2 laser to a million-dollar, multi-lens laser prepared for doing diverse sorts of things at the same time (Spence, 2005).

Previously, a smaller YAG set-up would begin at $125,000, yet have descended to the $40,000-and-up price range (Spence, 2005).

d. Ideal Application

The CO2 laser DPM systems are ideal for quartz, substrates like wood, Plexiglas®, glass, fabrics, ceramics, and other organics; further, the CO2 laser frequency range makes it viable for marking acrylic, wood, leather, and most plastics. Some metals, such as steel, stainless steel, and chrome, for example, can be marked by administering a chemical to the surface of the metal.

YAG lasers supply improved beam quality, exaggerated depth of focus, and better peak powers compared to fiber lasers, for fine marking, heat-temperamental materials and applications wherever higher consistency is needed.

[6] CerMark and Thermark are both laser-marking, bonding materials that help laser markings adhere to the item.

D. COST BENEFIT ANALYSIS

The primary price tag for achieving implementing machine-readable UID methods into approaching NSLC programs such as labeling, data plates, or DPM techniques will depend on a multitude of variants. The price tag will depend on the systems to be acclimated and whether this will be determined to be centralized rather than outsourced. The characteristics of the parts may very well alter the procurement cost of the chosen application technique. For example, factors like item geometry and the properties of the external marking surface may further alter the costs involved. There are likely to be nonrecurring and recurring costs to properly manage and determine the life-cycle costs involved with each part.

In 2005, the DOD oversaw a study, a cost to benefit analysis, regarding UID implementation for inclusion in its supply chain. The cost benefit analysis was meant to compare the price of in-house item marking against the outsourced price of marking the part. The cost comparison data for these methods can be found in Tables 1 and 2, respectively (United States Department of Defense, 2005). The tables show that the costs for in-house utilization are much less than that of outsourcing, but the initial set-up costs is markedly high. Tables 3 and 4, respectively, have been adapted from Tables 1 and 2, and adjusted for inflation, based on the Naval Center for Cost Analysis (NCCA) Joint Inflation Calculator (JIC) (NCCA, 2014). While these tables do not reflect all of the marking methods identified in this document, they are very representative of the costs involved, on average.

Table 1. In-House Part Marking Costs (after OUSD AT&L, 2005).

Table 1. In-house part marking costs.

Marking Approach	Method	In-house Marking costs (very dependent on order quantities)	Minimum Infrastructure to take advantage of UID and AIDC (optional)
Life-lasting gummed labels	Polyester	\$2000 printer + \$700 software + \$0.05 per label	Readers: \$500 →\$1000 per reading device
	Metal Foil	\$2000 printer + \$700 software + \$0.05 per label	Readers: \$500→\$1000 per reading device
Data Plates	Plastic	\$5000 machine + \$0.50 per label (very low volume)	Readers: \$500→\$1000 per reading device
	Metal	\$20,000 laser + \$0.50 per plate	Readers: \$500→\$1000 per reading device
Direct Part Marking	Inkjet	\$10,000 machine + \$0.50 per mark	
	Chemical Etching	\$2000 printer + \$300 chemetch + \$700 software + \$0.50 per mark	All methods (except laser bonding) will require more expensive low-contrast readers costing \$1200→\$2500 per reading device
	Dot Peening	\$10,000 machine + \$0.10 per mark	
	Laser Bonding	\$15,000 laser + \$0.30 per mark	
	Laser Etching	\$25,000 laser + \$0.20 per mark	

Internal Market Research: Survey of representative sample of marking companies

In-house marking costs are based upon non-complex part geometries and conditions for the part to be marked.

Table 2. Outsourcing Part Marking Costs (after OUSD AT&L, 2005).

Table 2. Outsourcing part marking costs.

Marking Approach	Method	Outsourced Marking Costs[a]	Minimum Infrastructure to take advantage of UID and AIDC (optional)
Life-lasting gummed labels	Polyester	\$0.10→\$0.50 per label	Readers: \$500→\$1000 Per reading device
	Metal Foil	\$0.20→\$1.00 per label	Readers: \$500→\$1000 Per reading device
Data Plates	Plastic	\$0.50→\$2.00 per plate	Readers: \$500→\$1000 Per reading device
	Metal	\$0.50→\$3.00 per plate	Readers: \$500→\$1000 Per reading device
Direct Part Marking	Inkjet Chemical Etching Dot Peening Laser Bonding Laser Etching	\$1.00 per mark \$2.00 per mark \$3.00 per mark \$2.00 per mark \$2.00 per mark	All methods (except laser bonding) will require more expensive low-contrast readers costing \$1200→\$2500 per reading device

Internal Market Research: Survey of representative sample of marking companies

Outsourced marking costs are based upon non-complex part geometries and conditions for the part to be marked.

Table 3. In-House Part Marking Costs (Inflation Adjusted) (after OUSD AT&L, 2005).

Table 3. In-house part marking costs (Inflation adjusted).

Marking Approach	Method	In-house Marking costs (very dependent on order quantities)	Minimum Infrastructure to take advantage of UID and AIDC (optional)
Life-lasting gummed labels	Polyester	\$2600 printer + \$905 software + \$0.07 per label	Readers: \$650 →\$1300 per reading device
	Metal Foil	\$2600 printer + \$905 software + \$0.07 per label	Readers: \$650→\$1300 per reading device
Data Plates	Plastic	\$6500 machine + \$0.60 per label (very low volume)	Readers: \$650→\$1300 per reading device
	Metal	\$26,900 laser + \$0.60 per plate	Readers: \$650→\$1300 per reading device
Direct Part Marking	Inkjet	\$12,940 machine + \$0.60 per mark	
	Chemical Etching	\$2600 printer + \$390 chemetch + \$905 software + \$0.60 per mark	All methods (except laser bonding) will require more expensive low-contrast readers costing \$1550→ \$3235 per reading device
	Dot Peening	\$12,940 machine + \$0.13 per mark	
	Laser Bonding	\$19,410 laser + \$0.40 per mark	
	Laser Etching	\$26,900 laser + \$0.30 per mark	

Internal Market Research: Survey of representative sample of marking companies adjusted for inflation.

In-house marking costs are based upon non-complex part geometries and conditions for the part to be marked.

Table 4. Outsourcing Part Marking Costs (Inflation Adjusted) (after OUSD AT&L, 2005).

Table 4. Outsourcing part marking costs (Inflation adjusted).

Marking Approach	Method	Outsourced Marking Costs	Minimum Infrastructure to take advantage of UID and AIDC (optional)
Life-lasting gummed labels	Polyester	\$0.13→\$0.65 per label	Readers: \$650→ \$1300 Per reading device
	Metal Foil	\$0.26→\$1.30 per label	Readers: \$650→ \$1300 Per reading device
Data Plates	Plastic	\$0.65→\$2.60 per plate	Readers: \$650→ \$1300 Per reading device
	Metal	\$0.65→\$3.90 per plate	Readers: \$650→ \$1300 Per reading device
Direct Part Marking	Inkjet Chemical Etching Dot Peening Laser Bonding Laser Etching	\$1.30 per mark \$2.60 per mark \$3.90 per mark \$2.60 per mark \$2.60 per mark	All methods (except laser bonding) will require more expensive low-contrast readers costing \$1555→ \$3235 per reading device

Internal Market Research: Survey of representative sample of marking companies adjusted for inflation.

Outsourced marking costs are based upon non-complex part geometries and conditions for the part to be marked.

We were provided a couple of pricing options after conversations with a couple of direct suppliers of UID equipment. We found that since we were not intending to actually purchase from these companies, they were not as forthcoming with pricing information and details as we would have liked, although these figures are below and more are in line with the average costs for the various respective UID marking techniques.

- A2B Tracking, a company that specializes in marking and tracking capabilities of critically managed assets, provided the following information:
    - A2B polyester labels, based on 20,000 labels per year. If the requirement were outsourced, each label would be approximately \$1.00-\$1.25 (D. Faria, A2B Tracking (personal communication, November 3, 2014))

- A2B polyester adhesive label costs:

UC! Web with one license	(annual cost) $9,500.00
Support	(annual cost) $1,500.00
Verifier	$9,000.00
Printer	$3,500.00
BarTender Software	$800.00
Scanner (wireless)	$1500.00
Blank labels (4000)	$500.00
Installation and Training	$5,500.00

- (D. Faria, A2B Tracking (personal communication, November 3, 2014)) Laser Photonics provided the following three options for laser applications:
  - Desktop with 20W fiber laser machine marking area 4”x 4” x and y capability for $28,000.
  - XP Compact model 20W fiber laser machine marking area 6” x 6” x, y, and z capability for $35,000.
  - Hand-held portable machine with 20W laser marking area 4”x 4” x and y capability for $29,000 (G. Zeqo, LaserPhotonics (personal communication, November 17, 2014)).

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V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

This project started with NSLC knowing that the current IUID labeling process on legacy items needed improvement and wanting to investigate other possible IUID marking methods that would help NSLC to be able to incorporate the remaining approximately 30 percent of items it has deemed not feasible to mark with IUID sticker-type labels. Currently, NSLC is experiencing problems with the adhesive on the labels placed on legacy items. High heat, high humidity, salt water exposure, and sailors removing the stickers on the equipment with ease are some of the flaws with the current IUID process. We conducted an onsite visit aboard USS *Fort Worth* (LCS 3), one of the first ships in the U.S. Navy that has labeled legacy items, and saw first-hand the issues associated with the current labels.

With the problem identified, we conducted a CBA on all the feasible ways that the Navy can label legacy and non-legacy items such as label printing, plastic and metal data plates, and various DPM methods. We contacted several contractors, such as A2B Tracking and Laser Photonics, all of which would follow the MIL-STD-130N for the markings, in order to conduct a thorough CBA and be able to provide sound recommendations for the future of IUID marking. In the CBA, we looked at both in-house production and outsourcing the labels, and also looked into the ideal applications for the DPM methods to be able to ascertain what would be of most benefit to the Navy in the long run.

B. CONCLUSION

Upon receiving the information from the contractors on the cost of the different methods in which the Navy can conduct IUID labeling, it was concluded that outsourcing the polyester labels with a strong adhesive from 3M, called Adhesive 300, would best benefit the Navy in labeling legacy items. Since it is recommended that legacy items be labeled with nonintrusive markings, the most cost-efficient technique would be to use polyester labels. In-house production of the labels would be less beneficial for the Navy in that every ship would have to pay for a license, installation, and training; for the software that will make the labels; and the unmarked labels and maintenance for the printer. Taking all the aforementioned variables into consideration, it would cost the Navy around $1.44 per label if the labels are produced in house. If the Navy outsources the labels, it would end up costing the Navy between $1.00 and $1.25 per label.

The labels would be ready-made and all the IUID technicians would have to do is place the label on the item, scan it, make any necessary changes on the database, and then upload it on the IUID registry. Outsourcing would also eliminate the need for ship's personnel to receive any specialized training or further creating a specific Navy Enlisted Classification to be able to maintain and operate the machinery associated with making the labels. Outsourcing the labels would also eliminate the possibility of not making the labels correctly by operator error or a software or hardware malfunction.

As there are many other methods by which NSLC could incorporate the remaining 30 percent of items requiring IUID marking, we determined that there is not just one other method, but a number of other methods that would need to be utilized to meet a 100 percent IUID marking standard.

C. RECOMMENDATIONS

We recommend outsourcing the polyester labels with the 3M Adhesive 300 for labeling legacy items. According to 3M, "the Adhesive 300 bond strength increases as a function of time and temperature, and has a very high initial adhesion" (2013, 2). The adhesive also has no negative effect when used on items that are submerged under water. Additionally, the adhesive bond strength actually increases after seven days at 90 degrees F and 90 percent relative humidity (3M, 2013). Under these conditions, the items could be labeled while the ship is in port or in maintenance availability, where the temperature is regulated. The 300 Adhesive by 3M is currently being used in the submarine community and, according to an NSLC contractor; it is difficult to remove even when using a flat-head screwdriver.

We recommend that NSLC further delineate what items still require IUID marking and decide on which marking method to invest in, based on the majority, or a couple of categories of the majority, of the items needing to be marked. By investing in just one other marking method, it is estimated that NSLC could possibly cover another 15 to 20 percent of the remaining items and, by investing in two other DPM methods, could cover an additional 5 percent for a total coverage of 95 percent. This means that NSLC could cover approximately 95 percent of all items requiring IUID markings by continuing to apply labels, and then invest in two other applicable marking methods.

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